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COMMUNICATION SYSTEM ANALYSIS

FOR MANNED SPACE FLIGHT

June 1, 1977 - August 1, 1978

Johnson Space Center

Houston, Texas

under

NASA Contract: NAS 9-13940

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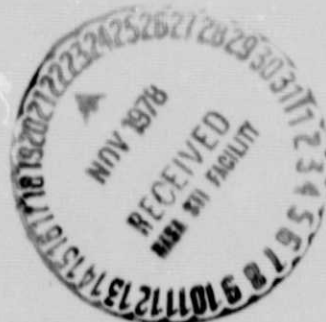
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DEPARTMENT OF ELECTRICAL ENGINEERING



THE CITY COLLEGE OF
THE CITY UNIVERSITY OF NEW YORK

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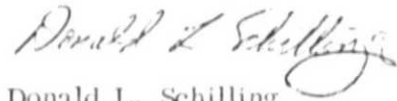
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Introduction

This report summarizes the development of adaptive delta modulators capable of digitizing a video signal. The delta modulator encoder accepts a 4 MHz black and white composite video signal or a color video signal and encodes it into a stream of binary digits at a rate which can be adjusted from 8 Mb/s to 24 Mb/s. The output bit rate is determined by the user and alters the quality of the video picture. The digital signal is decoded using the adaptive delta modulator decoder to reconstruct the picture.

Following a long history of cooperation between NASA and Dr. Schilling, an ADM system was delivered to JSC. The system is capable of encoding black and white or color video or encoding frame sequential color. The color signals were encoded at 24 Mb/s, the frame sequential color at 16 Mb/s and the black-and-white video at frequencies from 8 Mb/s - 16 Mb/s.

This Contract supported the following graduate students: R. Lei and N. Schoenberg.

VIDEO ENCODING USING ADAPTIVE DELTA MODULATION

ABSTRACT

This paper describes several adaptive delta modulators designed to meet NASA's potential need to digitally encode video signals.

The adaptive delta modulators described are:

- (1) One-dimensional ADM to encode black-and-white pictures and also transmit digitally encoded voice with no increase in bandwidth
- (2) An ADM to encode field-sequential color:
- (3) An ADM to encode color video signals.

The units described operate at bit rates that can be adjusted from 6 Mbps to 24 Mbps. The effects of the bit rate and channel errors on the response of the picture are discussed.

I. INTRODUCTION

It is often desirable to digitally encode a video signal. Such a signal can be transmitted with significantly less power (lower SNR) than an analog signal to obtain comparable quality of reconstructed signal. The digital signal can be easily encrypted to insure privacy and can, more readily, be stored in memory for applications requiring slow-scan video transmission.

There are many techniques available to digitally encode a video signal. They include PCM, Differential PCM, Transform Coding followed by PCM, and Adaptive Delta Modulation (ADM). This paper describes the research performed by the Communications System Laboratory at the City College of New York for NASA-JSC in the development of low cost, low bit-rate ADM's capable of encoding black-and-white and color video signals in the presence of high bit error rates. Our initial results and a summary of other techniques have been described in a previous paper.⁽¹⁾

Figure 1 shows a simplified picture of the video frame in which there are 500 lines/frame. If the video signal is bandlimited to 3.75 MHz, the Nyquist sampling rate is 7.5 M samples/s. Since the frame rate is 30 frames/s, the line rate is 15,000 lines/sec and, 500 samples are taken each line. There are therefore 250,000 samples in a frame. Each sample, as shown in Fig. 1, is called a pixel or pel.

When using PCM, 6-8 bits are transmitted for each Nyquist sample, with DPCM 3-5 bits are transmitted in the same time interval and using ADM we transmit 1-3 one bit samples during this time period. Thus ADM can operate at a lower bit rate than the other techniques.

ADM encoded video is relatively insensitive to channel errors. PCM noticeably deteriorates at bit error rates greater than 10^{-5} , while at 10^{-4} , the effect of channel errors is barely noticeable when using ADM and complete recognizability and intelligibility remains even at error rates as high as 10^{-2} .

Furthermore, ADM is a relatively low-cost system. The system shown in Fig. 2, constructed by DELTAMODULATION, INC., employs only 19 IC chips which fit on a single 7" x 8" printed circuit board.

II. THE ADM FOR VIDEO ENCODING

A block diagram of an ADM for video encoding is shown in Fig. 1. The input video signal $m(t)$ is sampled at or above the Nyquist rate to form $m(k+1)$. This sampled value is compared with the estimate $\hat{m}(k+1)$ where

$$e(k+1) = \text{sgn} (m(k+1) - \hat{m}(k+1)) \quad (1)$$

The estimate $\hat{m}(k+1)$ is formed from the old estimate $\hat{m}(k)$ and the step $S(k+1)$ which increments the estimate:

$$\hat{m}(k+1) = \alpha \hat{m}(k) + S(k+1) \quad (2)$$

Equation (2) shows that $\hat{m}(k+1)$ is found by passing $S(k+1)$ through a lossy accumulator, i.e., a narrowband digital low pass filter. The scalar $\alpha \approx 0.98$ insures satisfactory error correction in the decoder. ⁽¹⁾ In the encoder α can be set to unity without degrading the system performance.

The algorithm employed to generate the step $S(k+1)$ is

$$S(k+1) = \begin{cases} |S(k)| [e(k) + 0.5 e(k-1)] & S_0 \leq |S(k)| < 15 S_0 & (3a) \\ 2 S_0 e(k) & |S(k)| = S_0 & (3b) \\ 15 S_0 e(k) & |S(k)| = 15 S_0 & (3c) \end{cases}$$

S_0 is the minimum step-size and is equivalent to one quantization level. The maximum step is $\pm 15 S_0$, or 8 bits, as is the signal $m(k+1)$. Saturation logic is employed in the circuit used to generate Eq. 2 to prevent adverse effects when the adder overflows due to channel errors.

Encoding of a moving scene using the above ADM results in no distortion or other deleterious effects. Figure 4 shows the operation of this ADM at bit sampling rates of 6, 8, 16 and 22 Mbps. At 6 Mbps the "edge-busyness" is seen to be extremely pronounced and the writing Epoxy Super Glue on the card is not legible. At 8 Mbps (approximately 1 bit/pel) the edge busyness is reduced significantly but the writing is not quite legible. At 16 (approximately 2 bits/pel) and 22 Mbps the "edge-busyness" is no longer noticeable and the writing is legible. Note that the improvement obtained when increasing from 16 to 22 Mbps is not significant.

Figure 5 shows the response of the ADM to channel errors when the video signal is sampled at 20 Mbps. Figure 5a-e shows the response of the ADM when the $P_o = 0$ to $P_o = 10^{-2}$ respectively. An occasional error is observable at 10^{-3} while the presence of errors is quite noticeable at $P_o = 10^{-2}$. The response of the ADM to a uniform gray background in a high noise environment ($P_o = 10^{-2}$) is shown in Fig. 5f.

Note that the errors do not cause the picture to "break-up", i.e., they do not significantly affect the horizontal or vertical synch pulses even at an error rate of 10^{-2} . The errors, instead, act like an "overlay" of horizontal streaks and one has the feeling that if the overlay could be removed a "clean" picture would result.

III. ENCODING COLOR SIGNALS

A. Field Sequential Encoding of Color Signals

A field sequential color system is illustrated in Fig. 6. In this system the ADM encodes sequentially, the red, green and blue signals available at the camera output. For example, during the first field the red color is encoded, during the second field the green color is encoded and, during the third field the blue color signal is encoded. Along with the simplicity of the color camera, the advantage of this type of color system is that the bit rate

is the same as for black-and-white pictures.

The ADM was constructed and tested at JSC in a field sequential system. Figure 7 shows the straight-through and ADM encoded responses when using a field sequential system.

The disadvantage of this system is that only one color signal is encoded from each field and the color components of the picture tend to separate at the edges of moving objects. The color frame rate is only 10 frames/second. Except for this defect, which is characteristic of any field sequential system, there is no apparent distortion added by the ADM. Since edge busyness is a random function and a characteristic of these ADM's, it is interesting to note that the busyness is masked by the superposition of the three color frames.

B. Direct ADM Encoding of NTSC Video

The ADM characterized by Eqs. 1, 2 and 3 can be used to encode NTSC color video signals. Figure 8a shows the straight response of the system without the ADM. The picture used was taken from an afternoon "soap opera". Figure 8b shows the same picture encoded at 16 Mbps. The pictures were taken at a rate of 1/30 second which resulted in the diagonal streaks shown. Note the slight edge busyness and the granularity that is present. Also, observe the slight loss of detail in the necklace.

Figure 9 was taken from a morning quiz program. Such programs generally have extremely vibrant colors. Note again the presence of the diagonal streaks. These pictures were taken at a sampling rate of 24 Mbps.

In general the actual picture quality is much better than that observed from these figures.

C. Encoding Using Deemphasis Filtering

The ADM has a tendency to slope overload if the incoming signal has large high-frequency components. To avoid slope overload one can increase the bit rate. Alternately, one can low pass filter the signal prior to encoding, thereby decreasing the amplitude of the high-frequency portion of the video spectrum. Such a filter is called a "deemphasis" filter. In the receiver the ADM decoder is followed by a "preemphasis" filter to restore the the high frequency components of the signal.

Unlike FM where the deemphasis filter is a single-pole RC low pass filter, the deemphasis filter needed for color encoding must be a multiple pole filter. Several filters were attempted. The filter selected is shown in Fig 10a, Fig 10b shows the system configuration while Fig 10c shows the circuit used for each section. The values of L and C determine the Q of the section and the series resonance. The values of Q and the resonant frequencies were chosen to optimize the tradeoff between ripple and high frequency noise.

Figure 11a shows the straight through response of an NTSC color system, Fig. 11b shows the response of the direct encoded ADM at 24 Mbps and Fig. 11c shows the response of the ADM when deemphasis filtering is employed at the encoder at the same sampling rate. Note that the skin complexion is greatly improved when using deemphasis/preemphasis filtering.

D. Digital Voice and Video Multiplexing

It is often convenient to transmit voice simultaneously with the video signal. This is readily accomplished without any increase in bit rate.

The ADM described above encodes the composite video signal, i.e., the video information and the horizontal and vertical synch pulses. Since the synch pulse is a large negative pulse the ADM goes into saturation and generates a long stream of 0's. When operating at 20 Mbps approximately 80 0's occur consecutively.

If voice is encoded at the rate of approximately 32kbps, 2 bits of voice can be transmitted during each horizontal sync pulse. For example, to send the encoded bit 1 0 we add a header 1 1 1 to the bits and add the five bits 1 1 1 1 0 to the all-zero bits encoding the horizontal retrace. The result is the transmission of 32 kbps voice with 20 Mbps video with no increase in bit rate. It should be clear that data as well as voice can be multiplexed in this way.

The video encoder/decoder with an audio channel designed by DELTAMODULATION, INC. (Model 210) transmits a 3-bit code for each information bit of the digital voice thereby providing simple, yet effective, single-bit error-correction.

IV. NEW AREAS OF RESEARCH

A. Line Sequential Color Encoding

The difficulty with field sequential color encoding is that during periods of rapid motion, the color in each field will not line up; after all it takes 1/60 second to encode an entire field.

The above problem can be significantly reduced by encoding a different color for each line. For example, encode the red color of line 1, the green color of line 3 and the blue color of line 5. Use these three colors on line 3 of the monitor. Next encode the red color of line 7 and display the three colors of lines 3, 5 and 7 on line 5 of the monitor, etc. This system is now being constructed and will be tested at JSC.

B. Slow-Scan Video Encoding

PCM encoded slow-scan systems require a frame of digital memory in the transmitter and in the receiver. When ADM encoding is employed only the 1/3 bit stream need be encoded. Thus, the amount of memory required is reduced by a factor of approximately 4.

A slow-scan ADM system has been designed and is currently being

constructed for testing at JSC.

V. CONCLUSIONS

Once one realizes that a digital system costs no more and often less than an analog system, is more reliable and provides higher quality performance at significantly lower SNR, the conclusion is usually reached to "go-digital".

Two drawbacks to a digital system do exist. The digital system often requires wider bandwidth and, ECL devices often limit the speed at which digital circuit can operate to values which are less than desired.

When investigating which digital system to employ we must consider cost as well as quality. If commercial or near commercial quality is required, if recognizability and intelligibility are important, if small size, low power and low cost are factors worthy of consideration and sufficient bandwidth is available, then one should, as NASA is doing, look at ADM.

In this paper we have extended the results of our original paper ⁽¹⁾ and looked also at color video and audio on video. The results obtained from all tests performed by NASA indicate a pleasant quality picture, which is not degraded by motion.

VI. REFERENCES

- (1) "ADM Systems for Video Encoding", T. R. Lei, N. Scheinberg and D. L. Schilling; IEEE Trans. on Comm. Vol. Com 25, No. 11, November 1977.

VII. PAPERS PUBLISHED

Scheinberg, N, D. L. Schilling and J. Garodnick, "Video Encoding Using Adaptive Delta Modulation", IEEE Transactions on Communications, Special Issue on Shuttle Communications, November 1978.

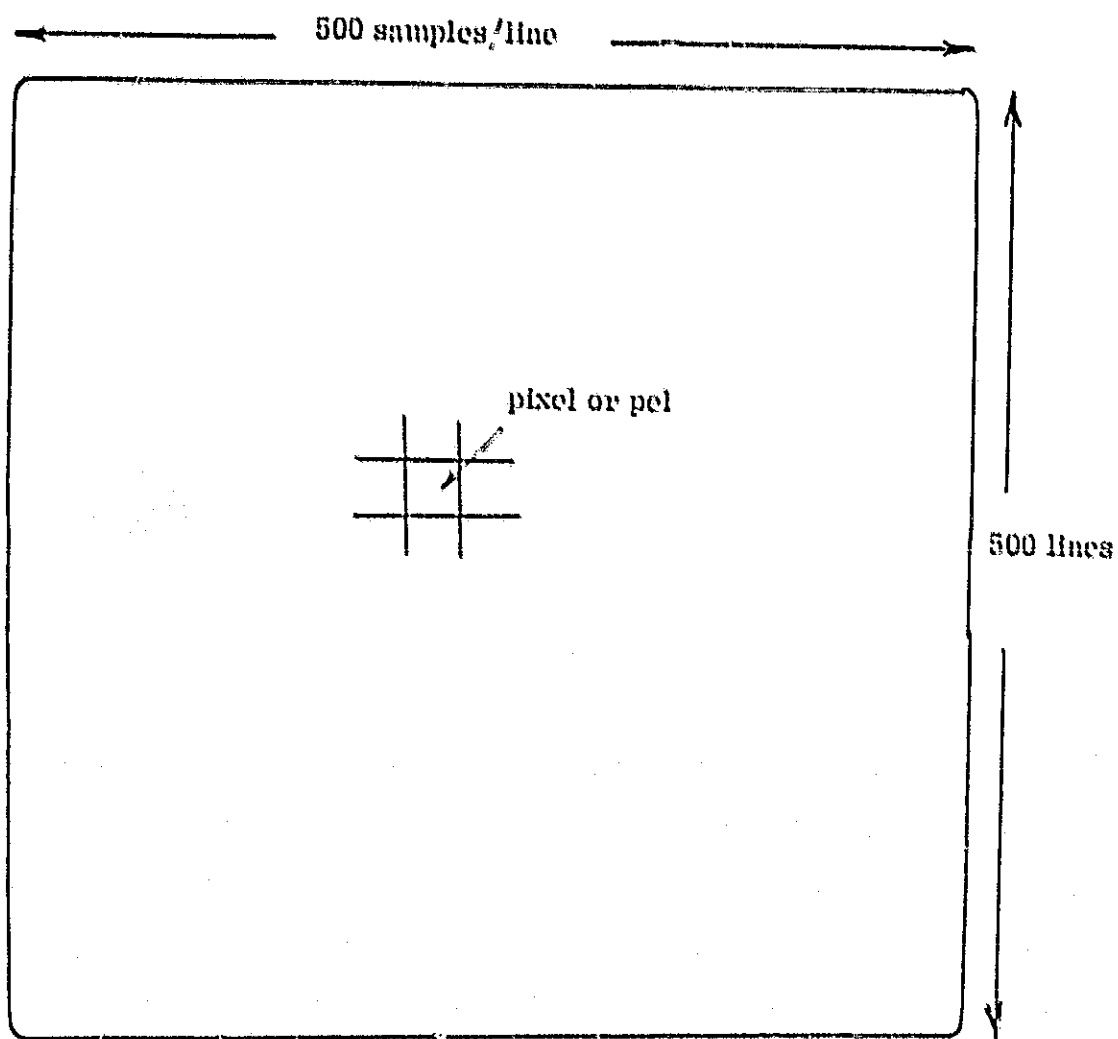


Fig. 1 Defining a pixel

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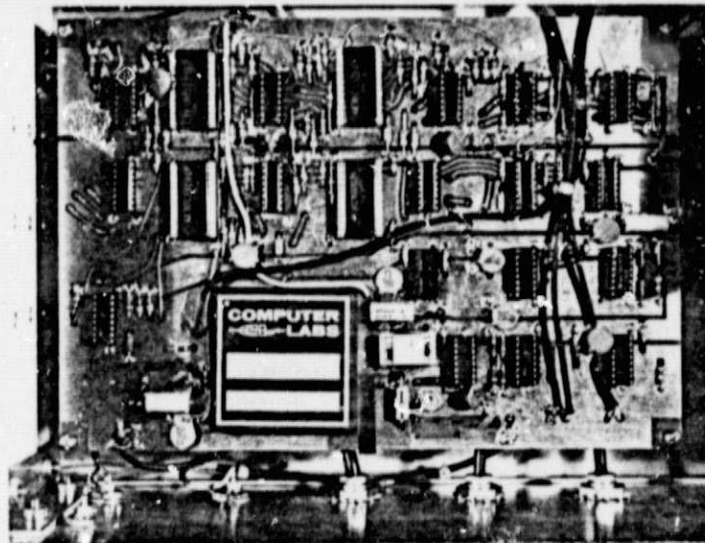
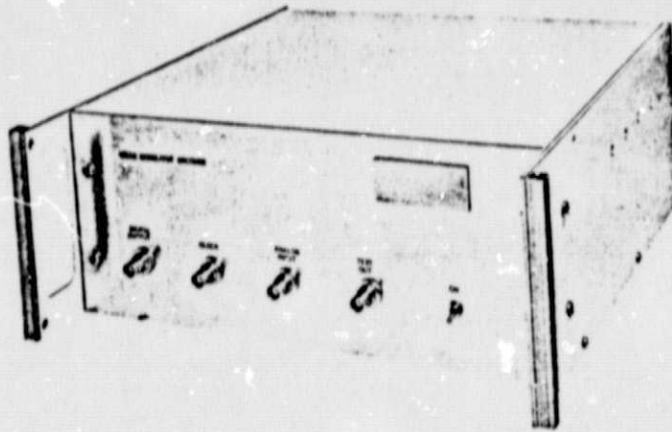


Fig. 2 (a) Adaptive Deltamodulator Model 200 manufactured by
Deltamodulation, Inc. (b) Circuit showing 19 IC construction.

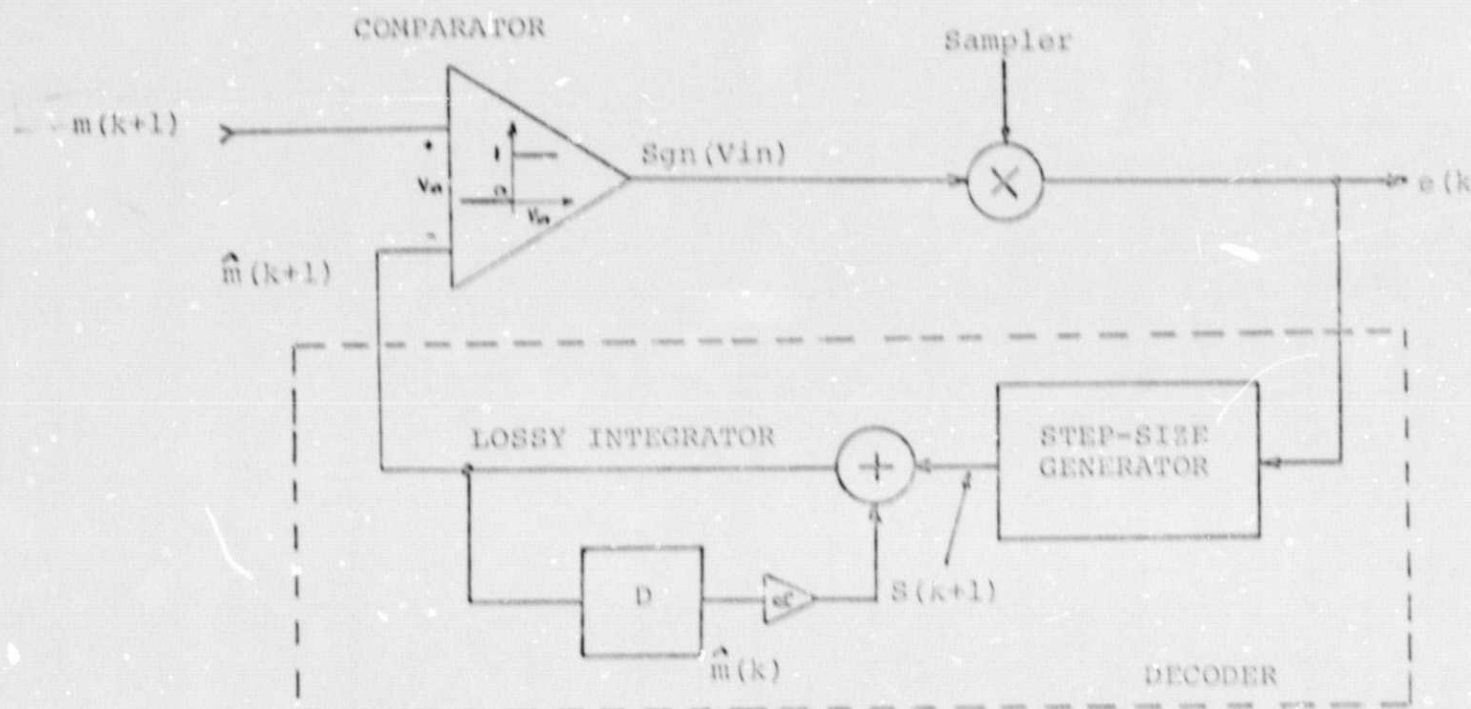


Fig. 3 ADM encoder and decoder.

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(a)



(b)



(c)



(d)

Fig. 4 Encoding at (a) 6, (b) 3, (c) 16 and (d) 22 Mbits/s.



(a)



(b)



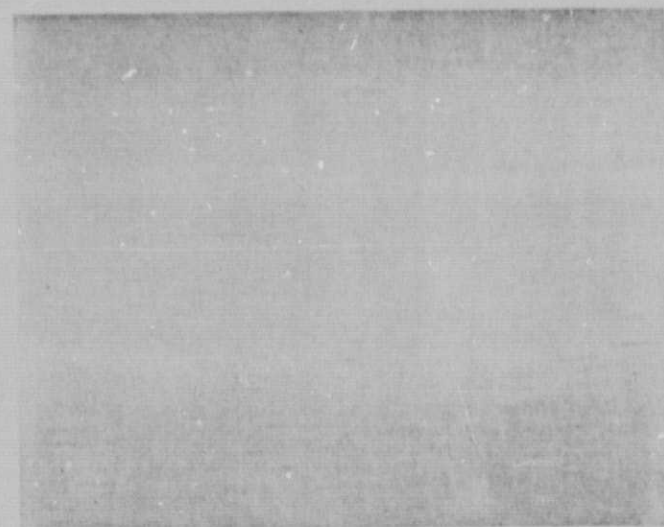
(c)



(d)



(e)



(f)

Fig. 5 Response of ADM to channel errors(s). (a) No errors, (b)

$P_e = 10^{-5}$, (c) $P_e = 10^{-4}$, (d) $P_e = 10^{-3}$, (e) $P_e = 10^{-2}$, (f) $P_e = 10^{-2}$.

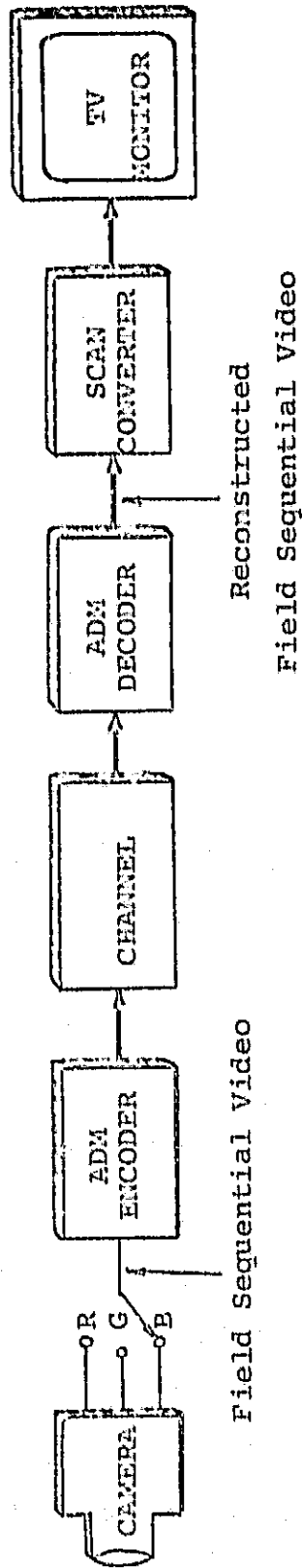


Fig. 6 Field Sequential Color System.

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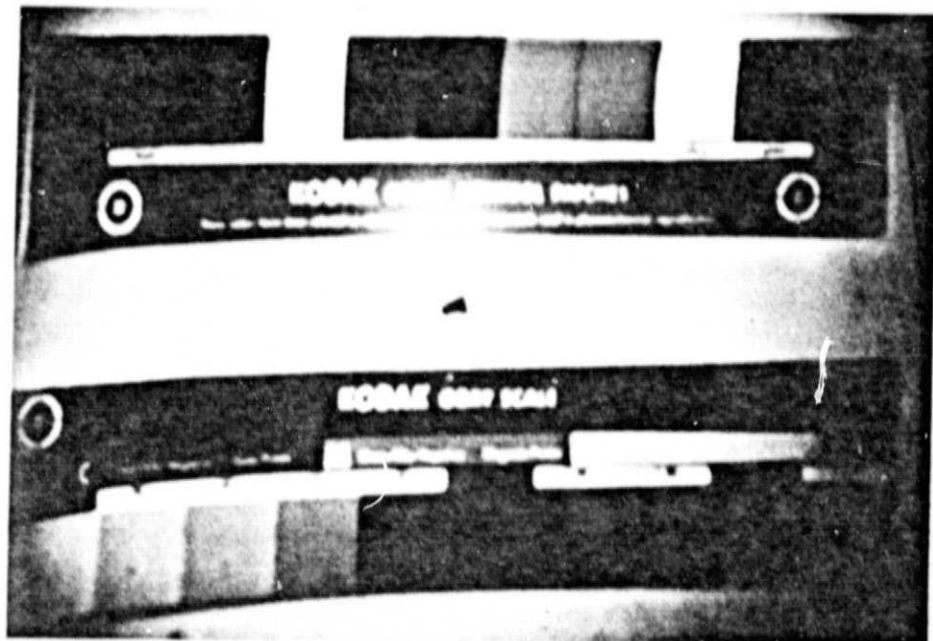
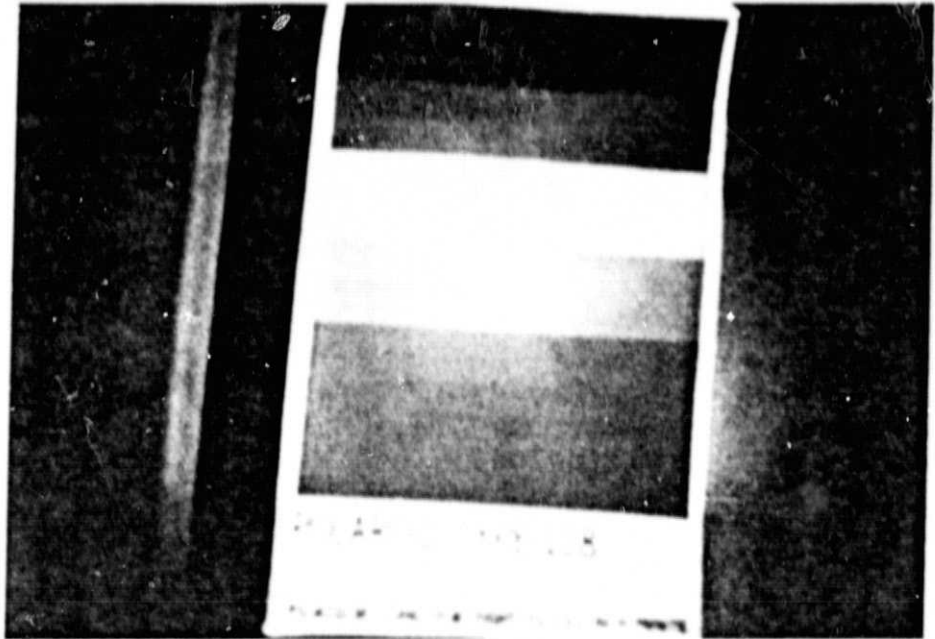


Fig. 7 Pictures obtained using Field Sequential Color. (a) Straight through response. (b) Encoded using ADM.



Fig. 8 Pictures obtained using NTSC Video. (a) Straight through response of color system. (b) ADM encoded picture at 15 Mbits/s.



Fig. 9 Pictures obtained using NTSC Video. (a) (b) Encoding at
24 Mbits/s.

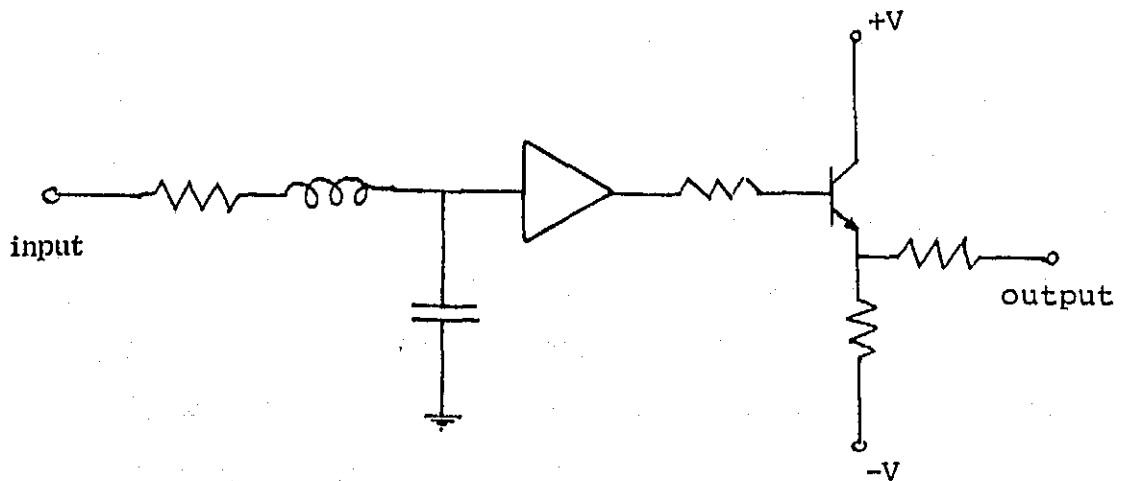
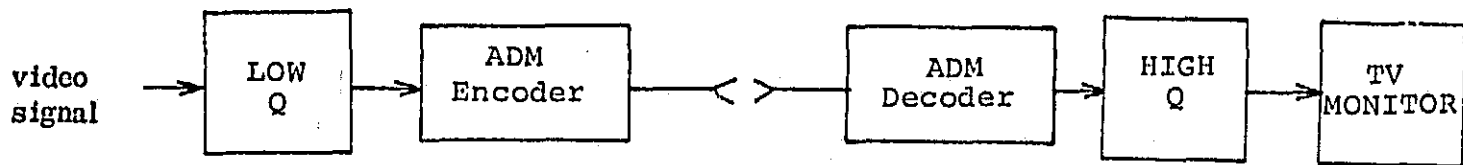
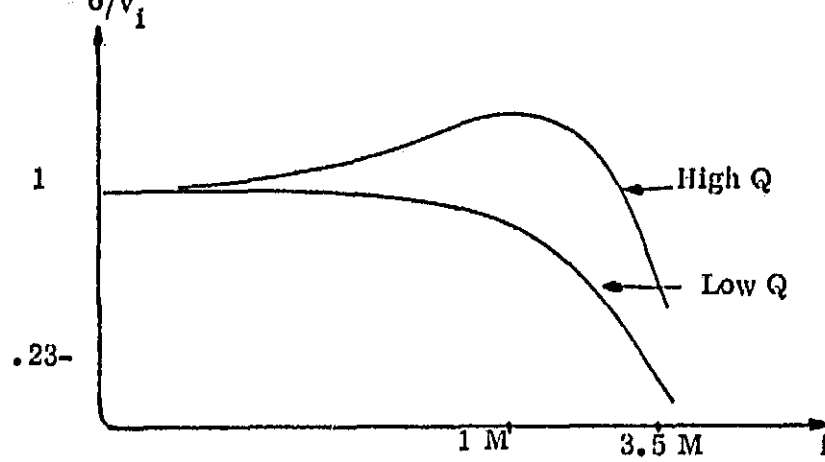


Fig. 10 Encoding using deemphasis filtering. (a) Amplitude vs.

Frequency. (b) System Configuration. (c) Low Q and High Q circuits.

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Fig. 11 Subjective effects of deemphasis filtering. (a) Straight through response. (b) Encoding using ADM. (c) Encoding using deemphasis filtering and ADM.